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Review of Innovative Sediment Delivery Systems

by Thomas D. Smith

PURPOSE. This Coastal and Hydraulic Engineering Technical Note (CHETN) provides a review of recent innovations in methods to deliver sediment to placement areas for Regional Sediment Management (RSM) activities such as beach nourishment projects.

BACKGROUND. Conventional sediment delivery methods used for beach nourishment or dredging projects typically fall into two categories: (1) vehicular transport (e.g., dump trucks), or (2) piped slurry transport systems. Truck hauling operations can transport wet or dry sediment from point to point, but often have problems accessing confined work areas. Trucks are often seen as disruptive to the general public and surroundings due to the continuous traffic and loud noises associated with construction vehicles. Damage resulting from the creation of access roads and from the continual heavy truck traffic often creates the need for significant site restoration after construction activities are complete. By contrast, pipeline systems transport the dredged sediment in the form of a sand-and-water mixture known as a “slurry.” The sediment fraction is usually on the order of 10 to 20% by weight of the slurry, which creates a significant dewatering issue at the discharge location.

Recently developed sand transport and delivery methods use advanced air blowing techniques to convey the sediment through a pipeline system without the addition of water. Similarly, covered conveyor belt systems allow wet or dry sand to be transferred along narrow easements and to be discharged directly to the stockpile or placement area. Other technologies currently being developed, that are currently either not yet being fully employed or are being minimally used for sand transport, show great potential for effective use as sediment delivery systems.

This RSM Technical Note describes the conventional state-of-the-art of beach sediment transport technology and reviews innovative sediment delivery systems presently under development. Information contained here is based on both a review of the technical literature and on direct input from private sector contractors and developers.

CONVENTIONAL SEDIMENT DELIVERY SYSTEMS.

Truck Haul System. One of the most common forms of sand transport and delivery for beach nourishment is by truck haul (Dean 2002). This method involves the mechanical loading of dump trucks with wet or dry sand, which then transport the material to a beach or other stockpile location. Haul trucks for this application typically carry 12 to 18 cu yd of sediment. An advantage to this system is that, in theory, once sand is loaded into the dump trucks, it is contained until the final stockpile location at the end of the system. However, larger projects have the potential to significantly damage public roadways due to the repetitive movement of heavy vehicle traffic.

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The Waikiki Beach nourishment project, Honolulu, HI (Figure 1), in 2012 used 26-ton-capacity articulated off-road dump trucks to transport 24,000 cu yd of sand up to 2,500 ft along the beach from the dewatering basin/stockpile site. Working 5 hrs/day, three trucks could move 1,500 cu yd of sand for final placement and grading. Safety was a major concern on this crowded beach, and extensive use was made of safety fencing and human traffic guards to keep the surfers and trucks separated (Figures 2 and 3).

Slurry Pipeline System. For dredging or beach nourishment projects where the borrow source is relatively close to the placement location, a piped slurry is often employed for transporting the material (Dean 2002). This type of sediment transport requires the borrow material to be submerged, which allows the hydraulic dredge to suspend the sand within the water column using a combination of agitation and suction, thus creating a sand-water slurry that is typically between 10 and 20% sand by weight. Under controlled conditions and with uniform sand free of rocks, cobbles, and other debris, transport rates up to 50% sand by weight are possible. The slurry is pumped ashore or to the desired location via pipeline to a dewatering area to allow settling of fines and silt before the water drains back to the source river, lake, or ocean. This is a mitigation procedure often required by environmental water quality regulations.

Figure 1. Waikiki Beach, Oahu, HI.

During transport, velocities within the flow must be sufficient to keep the largest grain size fractions entrained; otherwise, the grains may fall out of suspension and begin to clog the pipeline. Maintaining the necessary flow rate can become energy intensive for larger projects, with required power increasing exponentially with pipe diameter. A number of inefficiencies exist with piped slurry transportation systems, the primary one being that typically 80 to 85% of the energy consumed is spent on moving water that is otherwise unused, and furthermore may be classified as an environmentally harmful byproduct at the endpoint.


Figure 2. Truck hauling.

Slurry pipelines are often used in sand bypassing systems that protect navigation projects from natural siltation and sand accretion. Man-made structures such as dredged navigation channels, jetties, and dams act as barriers to the migration of sand under natural processes, resulting in an impoundment of sediment at these locations. To mitigate the buildup of material at these locations, sand bypass or sand transfer facilities have been used to hydraulically dredge the material and transfer the sand slurry via pipeline to a down-drift placement location.


Figure 3. Pedestrians crossing.

INNOVATIVE SEDIMENT DELIVERY SYSTEMS.

Pneumatic System. Pneumatic (air) conveyance systems are commonly used in industrial settings to transfer bulk materials such as grain, cement, fly ash, and other dry bulk products, typically over short distances (Wypych 2011). Recently, a firm known as EcoSensitive Solutions, Puyallup, WA, advertised the application of a unique pump technique using the AirVeyor© specifically to pneumatically convey sand and other sediments over long distances. An excerpt from EcoSensitive Solutions promotional literature describes the process:

> The material to be conveyed is fed into the inlet hopper section (Figure 4) of the pump (Figure 5), and an auger imparts an initial mechanical velocity towards an acceleration cone. The bulk materials are then introduced into an inline or linear flow of low pressure, high velocity air moving past the end of the auger barrel towards the conveying pipeline where it moves into the center of the high velocity air stream. It is reported by manufacturers/operators of this equipment that regardless of variations in the shape, size, weight, or type of material, the entire mass moves and behaves within the system as though it was a homogeneous gas. The conditions created tend to separate and keep the material particles from touching each other and from touching the wall of the pipeline; thus, there is minimal degradation to the material being transported or to the pipeline itself as there is very low friction in the pipeline. The system is low pressure (2 to 8 psi), and reportedly can move material through a pipeline as long as 3,000 ft and into hard-to-reach areas where it is discharged (Figure 6).

Figure 4. Loading sand into hopper.

Figure 5. Pneumatic pumping system.

Figure 6. Sand discharging from pipeline.

Sea Engineering, Inc. observed a demonstration of the EcoSensitive Solutions air conveyance system in December 2009. The pump system and approximately 1,000 ft of 8-in. High Density Polyethylene Pipe was staged in an abandoned quarry near Seattle, WA. Due to the small size of the demonstration area, the pipeline had to make a 180-degree turn halfway along its length. The pictures shown in Figures 4 through 6, taken at that demonstration, illustrate the system components and operation. It was estimated that approximately 40 cu yd per hr of wet sand were being conveyed through the pipeline (although no quantitative volume-rate measurement was made).

An attempt was made to use an air conveyance system to transport and place sand from the dewatering basin along 2,500 ft of beach during the 2012 Waikiki Beach nourishment project, prior to using the truck haul system. The construction specifications for the project required that "The dredged sand shall be conveyed from the dewatering basin along the shore for placement to the lines and grades shown on the drawings by means of a pneumatically driven, low pressure system capable of delivering wet sand through a pipeline to the required locations along the shoreline in the project area. Pressure in the pipeline shall not exceed 12 psi. The system must be capable of conveying a minimum of 100 cu yd of wet sand-sized material per hour over a maximum distance of 2,500 ft." It was thought that the air conveyance method of sand transport would be the best alternative for the very congested and heavily used Waikiki Beach. Figures 7 through 9 show the pneumatic system deployed at Waikiki Beach.

Figure 7. EcoSensitive Solutions system.

Figure 8. Feeding sand into hopper.

Figure 9. Pneumatic delivery system.

Unfortunately, the subcontractor responsible for providing and operating the air conveyance system was unable to perform in accordance with the project specifications. After several weeks of equipment trial, alteration, and still more trial, it became clear that the system was incapable of moving more than about 20 cu yd of sand per hour a distance of about 1,000 ft, far too slow a rate to effectively meet the needs of the project. Additional issues with the air conveyance system were noise generated by the pump (a high-frequency piercing noise similar to a jet engine starting up), and considerable fine dust at the pipe discharge, which drifted with the breeze. A decision was made to abandon the air conveyance system, and move the sand using the conventional truck haul methodology. Fortunately, the contractor was able to develop a truck haul system that minimized inconvenience to the beach users and the resort hotels, and that maximized safety. The ability to move large volumes of sand quickly by truck resulted in very rapid placement of the sand.

While the EcoSensitive Solutions website is presently offline, a promotional video can be found at http://www.youtube.com/watch?v=mDOAGtjge-8. There are no other known alternative providers of pneumatic sediment conveyance systems designed for use in beach or dredging projects although the system offers great promise with further development.

Conveyor Belt System. Recently, conveyor belt systems have been increasingly used for beach nourishment projects, especially where limited access and minimization of post-construction site restoration are significant issues. Conveyor belts have been used for beach nourishment projects on both the east and

west coasts of the United States. In 1988, 700,000 cu yd of dune sand were excavated from inshore dunes and delivered as nourishment to El Segundo Beach, CA during the expansion of the Hyperion Waste Water Treatment Plant. The conveyor belt snaked through an existing 9-ft-diam culvert under California Highway 1, the Pacific Coast Highway. The town of Palm Beach on Florida's Atlantic coastline recently placed 293,000 cu yd of beach nourishment via a conveyor belt that used narrow corridors between existing structures (Dean 2002).

Sand Transfer Systems (STS) is a primary supplier of project-ready mobile sand conveyor belt systems. STS has a collection of electrically powered conveyor belt units, each roughly 50 ft long, that can be linked together in series to accommodate varying transfer distances (Figure 10). At this time, the longest transfer of beach nourishment via the STS conveyor system has been 1,000 ft. However, STS states that limitation is based purely on the number of available conveyors. The system requires a minimum corridor width of 4 ft, and can be supplied at the entry point using a space with a minimum width of 12 ft. Maximum production rate is reported to be 600 tons per hr, roughly equivalent to 440 cu yd per hr, depending on sand density. The sand may contain up to 12% moisture content.

Figure 10. STS conveyor belt system.

A primary benefit of conveyor belt systems is their proven ability to deliver significant quantities of sand through challenging access corridors. Areas where shoreline erosion is most threatening are often the same areas where shoreline development and infrastructure are densest. Developed areas create access restrictions for heavy equipment to replenish the beach. A conveyor belt system can navigate densely developed areas by passing through narrow pathways, easements, or lawns, and thus avoid causing damage to the surroundings while still providing a respectable production rate.

The complete conveyor belt transfer system is assembled by linking the individual conveyor units in a cascading daisy chain, where the upstream conveyor feeds the material into the reception hopper of the next conveyor, allowing for a wide degree of flexibility in terms of alignment angles for each conveyor (Figure 10).

A dump truck feeds the primary supply hopper (Figure 11), which feeds the first conveyor in the chain. The last conveyor in the chain is able to rotate horizontally in a sweeping motion to facilitate spreading of the stockpile (Figure 12). This can be done either automatically or manually. The entire system is powered by a relatively quiet 230 kW power-pack. The complete STS conveyor system for up to 1,000 ft of transfer distance can be transported using three low-boy trailers, or three intermodal containers for shipping.

Alternative conveyor belt systems appear to be available from the growing hydraulic fracturing (fracking, shale gas recovery) industry, which use large quantities of sand as proppants that are pumped underground as a sand-water slurry under great pressure to prop open, or fracture, subsurface cracks and faults in the earth to stimulate release of natural gas for harvesting.

Figure 11. STS dump trucks supplying the feed hopper.

Figure 12. Cascading action of linked conveyor belts.

Figure 13. Wilson Manufacturing and Design, Inc. self-propelled system.

Figure 14. CAS remote controlled vehicle (AT7).

Industry manufacturers are supplying self-propelled, diesel powered conveyor belts (Figure 13) capable of carrying 200 tons of aggregate material (with diameters up to 2 in.) per hour. This equates to roughly 150 cu yd per hr, depending on sand density. As fracking becomes more widespread, the supporting equipment such as mobile conveyors will likely become more commonly available, which will reduce costs, making them a possible option for beach nourishment projects when used in series similar to that shown in Figure 10.

Vehicle-Conveyor Hybrid System. New advances in bulk transport and handling are producing hybrid technologies that combine the mobility of vehicular transport with the agility of conveyor belt delivery. Conveyor Application Systems (CAS) is producing a line of tracked and wheeled conveyor systems that can sling moist or dry bulk material such as beach sediment from an integrated hopper, over large obstacles in a directed stream.

The CAS equipment has recently been used successfully in medium-scale shore protection projects along Florida's Atlantic and Gulf Coasts. For example, Figure 14 shows CAS's remote controlled vehicle (AT7) using its articulating conveyor to place sand fill behind a shore protection structure at a project in Palm Beach, FL. The AT7 is primarily used to quickly and efficiently sling sand (or other aggregate) into inaccessible locations that would be difficult to service with larger excavators (Figure 14). The hopper may be fed at the placement location, or it may be loaded at a nearby staging area and then driven remotely to the placement site.

The TR30 is a larger variant of the AT7 that features a tracked vehicular platform and increased hopper capacity. The TR30 is also designed to facilitate filling of geotextile tubes or flood control barriers (Figure 15). Both the AT7 and TR30 feature hoppers that may be fed by front end loaders, by stationary conveyors, or by any other means.

A third variant of this technology is CAS's Super Track, which is essentially a modified dump truck with an integrated conveyor capable of slinging dry bulk material such as sand or rock directly from its hopper-bed to the placement location (Figure 16). A benefit of this apparatus is that the same vehicle is used for long distance hauling and for final placement, which saves time and reduces labor.

Figure 15. CAS tracked loader (TR30) for geotextile tubes.

Figure 16. CAS Super Track, direct placement from truck.

Tubular Drag Conveyor System. Tubular drag conveyor systems are typically used to transport industrial bulk material within factories or plants. Although these systems are not currently used in the beach nourishment and sediment transport industry, the core technology of tubular drag conveyors offer a potential for use in these applications. The technology consists of a stationary outer casing through which a chain is pulled by a sprocket drive. Flights (circular disks) are attached to the chain at regular intervals. As this endless chain and flight assembly moves through the casing, bulk material (i.e., sand or gravel) is pulled from the feed location to the discharge port (Figure 17).

Figure 17. Tubular drag conveyor.

While similar in some ways to cable and aero-mechanical style conveyors, tubular drag technology is said to be superior to those systems since it uses a heavy-duty chain to move dense material at a low velocity, resulting in a rugged, virtually maintenance free, low power conveyance method. The typical tubular drag conveyor is operated by a single, low-horsepower electric motor, making the method very energy efficient. The slow-moving, positive displacement action of the chain assembly is ideal for handling gritty or sticky material such as wet sand. The tubular drag conveyor can operate continuously or intermittently, and its slow movement ensures long conveyor life, dependable service, and minimal noise levels.

Currently, the maximum diameter for the tube system, which can be fabricated from galvanized or stainless steel, is approximately 12 in. The maximum length of transport for a single system is approximately 400 ft, which can accommodate multiple changes in direction both horizontally and vertically. Conveying capacity is estimated to be up to 114 cu yd per hr, which may be adjusted by varying the casing and flight size as well as the speed at which the chain operates.

Limitations are that the system does not appear to be highly mobile; it is oriented more for factory usage. However, it appears that with some modifications, the system may be used effectively in certain beach nourishment projects with very limited access.

PASSIVE TRANSPORT OR SUPER NOURISHMENT. The concept of "Super Nourishment" is based on the principle of analyzing site-specific hydrodynamics. The system employs numerical wave, current, and morphology models to optimize an offshore stockpile placement site and geometry; once the stockpile is placed, natural processes are allowed to redistribute the beach material to the intended locations. Simply stated, Super Nourishment places a large amount of sand in a specific location and form so that it will be naturally transported to the desired place without human intervention, thus providing significant savings by reducing construction costs.

The passive transport idea was developed on a large scale in The Netherlands. A recent Dutch project involved the placement of 28.1 million cu yd of sand in the nearshore waters of Ter Heijde, in a specifically designed template resembling the shape of a hook that rises approximately 4 to 6 ft above sea level (the Sand Engine Project).

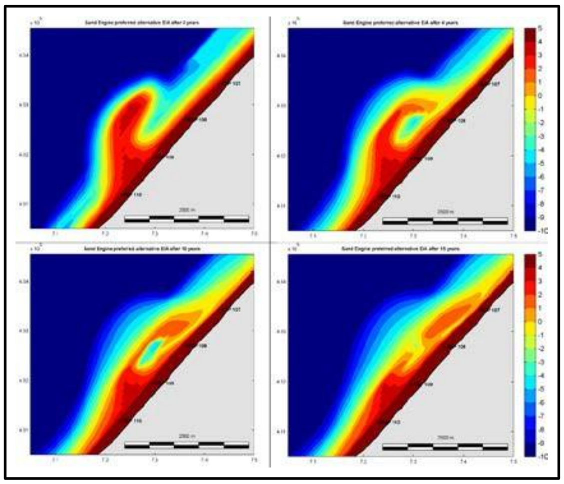

Figure 18. Numerical model of Sand Engine Project.

Figure 19. Sand Engine Project, Ter Heijde, The Netherlands, October 2011.

The shape was designed via morphodynamic modeling using the Simulating WAves Nearshore (SWAN) model coupled with the TRANSPOR2004 model to use predominant wind, waves, and currents to redistribute the deposit along the coast over time (Figure 18). SWAN is a hydrodynamic wave model developed by Delft University of Technology for modeling wave propagation, shoaling, refraction, and many other wave behaviors. TRANSPOR2004 is a sediment morphology model used for computation of sand transport under current and wave conditions, implemented in the software Delft3D-ONLINE. Construction of the Super Nourishment was completed in 2011; over time, it will gradually change in shape, eventually becoming fully incorporated into the dunes and beach to uniformly widen the beach over a length of approximately 2.5 miles.

By depositing a large amount of sand in a single operation and allowing natural forces to redistribute the sediment to the intending location, the project aims to prevent repeated disruption of the vulnerable seabed. Natural forces will gradually take the sand to the desired location. If the Sand Engine Project fulfills expectations, sand replenishment off the Delfl and Coast will be unnecessary for the next 20 years. (Previously it was necessary every 5 years.) Figure 19 shows the Sand Engine Project near the end of construction, with observations indicating that the hook form was already beginning to mobilize.

Although not applicable for most typical small- to medium-scale beach nourishment projects, Super Nourishment seems to be well suited for very large scale projects along relatively straight and homogenous shorelines such as found on the US east and Gulf coasts. Shoreline reconstruction following major hurricane damage may be one possible application in the United States. More information pertaining to the Sand Engine Project is available in Mulder and Tonnon (2010), Dredging Today (2011), and Dutch Water Sector (2011).

The US Army Corps of Engineers (USACE) has established a strategy to foster environmentally friendly projects similar to the Sand Engine Project approach in the United States through implementation of the Corps' Engineering With Nature (EWN) program (USACE 2012). The program is intended to align natural forces and engineering processes to efficiently and sustainably deliver economic, environmental, and social benefits through collaborative processes, including: (1) strategic placement of sediments for beneficial use of dredged material (making use of hydrodynamics and natural transport processes to build nearshore habitats); (2) use of engineering features to focus natural processes to minimize navigation channel infilling, and to transport and focus sediments for positive benefits; and (3) optimizing the use of natural systems such as wetlands and other features to reduce the effects of storm processes and sea level rise on shorelines and coasts.

SUMMARY. This CHETN describes the conventional state-of-the-art in beach sediment transport and reviews innovative sediment delivery systems presently under development, specifically as they relate to beach nourishment and RSM programs. In addition to the conventional methods of truck hauling and pipeline slurry transport, there are emerging alternative technologies and methods such as pneumatic, conveyor belt, vehicle-conveyor hybrid, and tubular drag conveyor systems. Also, a concept for passive transport, or "Super Nourishment," allows the placement of a large amount of sand in a specific location and form so that it will be naturally transported to the desired place with no human intervention. This passive transport concept is consistent with the USACE strategy to foster environmentally friendly projects through implementation of the Corps' EWN program.

ADDITIONAL INFORMATION. This CHETN was produced by the US Army Engineer District, Honolulu, HI (POH), as part of the USACE RSM program, and was written by Thomas D. Smith, POH. Additional information regarding the RSM can be found at the Regional Sediment Management website: http://rsm.usace.army.mil.

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ACRONYMS AND ABBREVIATIONS.

Term	**Definition**
CAS	Conveyor Application Systems
CHETN	Coastal and Hydraulics Engineering Technical Note
CHL	Coastal and Hydraulics Laboratory
ERDC	Engineer Research and Development Center
EWN	Engineering With Nature
POC	Point of Contact
POH	US Army Engineer District, Honolulu, HI
RSM	Regional Sediment Management
STS	Sand Transfer Systems
SWAN	Simulating WAves Nearshore
US	United States
USACE	US Army Corps of Engineers